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UNDERSTANDING THE DISEASE

Hemodynamic impact of prone position. Let's protect the lung and its circulation to improve prognosis

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Hemodynamics is a key factor in the management of acute respiratory distress syndrome (ARDS), as hemodynamic compromise is associated with mortality and its incidence is between 50 and 70% [1]. In around one half of ARDS patients with hemodynamic compromise, the main mechanism is right ventricular (RV) failure related to an abrupt increase in pulmonary vascular resistance with loss of perfused vascular tissue bed because of microthrombi, pulmonary vasoconstriction, and endothelial dysfunction, but also because of the consequences of mechanical ventilation itself with its generated excessive transpulmonary pressure. In the other half of patients, hemodynamic compromise is due to sepsis, which is frequently associated with ARDS. The Berlin Consensus defined ARDS and recommended a respiratory strategy, unfortunately only based on the PaO_2/FiO_2 ratio without any mention of hemodynamic status [2]. A more recent guideline recommended avoidance of excessively high a positive end-expiratory pressure (PEEP) when it induces hemodynamic worsening [3]. This high PEEP strategy, when combined with an aggressive recruitment maneuver, worsens hemodynamics and increases mortality [4]. Hemodynamic failure interferes with blood gases which seriously limits the evaluation of ARDS severity based on oxygenation. A low cardiac output at constant shunt can overestimate the degree of lung injury by decreasing PaO_2 through a decrease in PvO_2; conversely, it can decrease the computed shunt fraction, thus underestimating severity; finally, RV overload can re-open the patent foramen ovale leading to intracardiac shunt.

Prone position significantly improves the prognosis of moderate to severe ARDS with a $PaO_2/FiO_2 < 150$ mmHg [5] and some experts have already highlighted its impact on the lung [6]. However, very little consideration was given to its crucial impact on hemodynamics, and especially on the pulmonary circulation. Besides its ability to decrease ventilator-induced lung injury (VILI), which potentially contributes to increased survival, prone position also improves hemodynamics by its ability to limit the risk factors for RV failure, which may also participate in its beneficial effect.

In the Proseva trial, lower incidence of cardiac arrest was reported in the proning group as well as more cardiovascular dysfunction-free days up to 28 days after randomization, while no information was given on RV function [5]. In a small series of 18 cases of moderate to severe ARDS, Jozwiak et al. reported that pulmonary vascular resistance decreased in all patients and cardiac index increased in half of them [7]. Interestingly, all patients had a dilated right ventricle before proning, suggesting some degree of increased afterload. In 2007, Vieillard-Baron et al. reported in 42 patients with severe ARDS that in the 50% who developed acute core pulmonale (ACP) an 18-h session of prone position corrected RV overload, with an increase in cardiac index. In the other half, no hemodynamic modification was observed [8].

This beneficial hemodynamic effect of prone position on RV function, especially when the right ventricle is previously overloaded, is explained as follows. Proning increases PaO_2/FiO_2 ratio, while a ratio below 150 mmHg

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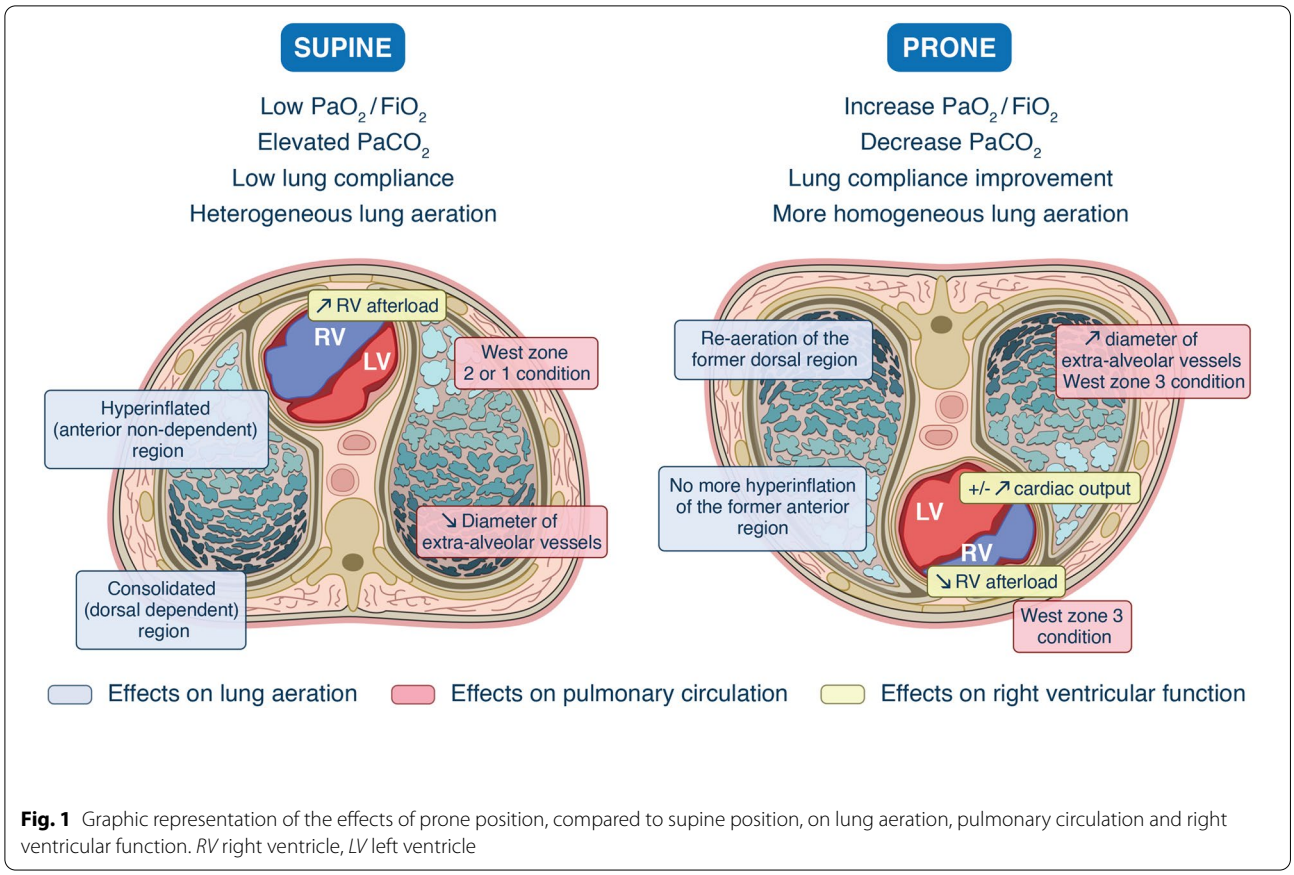

Fig. 1 Graphic representation of the effects of prone position, compared to supine position, on lung aeration, pulmonary circulation and right ventricular function. *RV* right ventricle, *LV* left ventricle

has been reported to be associated with the development of ACP [9]. Proning also decreases $PaCO_2$, while a $PaCO_2$ higher than 48 mmHg is also associated with the development of ACP [9]. Gattinoni et al. suggested that improved CO_2 clearance could indicate a beneficial effect of prone position on the outcome in ameliorating the distribution of ventilation/aeration in the lung [10], although this was not confirmed by the Proseva trial [11]. Proning also improves lung compliance, thereby decreasing plateau pressure and driving pressure, which are both also risk factors for RV overload. In ARDS, at least in the early phases, the lung is non-homogeneously aerated. Hyperinflated regions move lung areas from West zone 3 to zone 2 or even zone 1, leading to RV overload [12]. In contrast, atelectatic lung also induces RV overload due to the decrease in diameter of the extra-alveolar pulmonary vessels, which is corrected by re-aeration of the lung [13]. These combined deleterious effects on the pulmonary circulation are illustrated by the so-called U-shape relationship reported between transpulmonary pressure and pulmonary vascular resistance. By proning, the lung becomes mechanically more homogeneous with a decrease of both hyperinflated (anterior non-dependent in supine) and non-aerated (dorsal and dependent in supine) regions (Fig. 1). As previously said, prone position in itself might also be a major determinant of the decreased risk of VILI, a well-reported risk factor for RV overload [14].

Another potential benefit of proning for hemodynamics is that the commonly observed oxygenation improvement could justify the use of lower PEEP levels. Excessive PEEP may overload the right ventricle. With proning, the dorsal regions of the lung (a major proportion of the total) may benefit from increased local transpulmonary pressure, which is usually too low in the supine position, by a decrease in pleural pressure. In the supine position, a higher PEEP is necessary to achieve the same effect, at the expense of the already aerated regions, which now become hyperinflated [15]. Proning therefore achieves better effects than a higher PEEP without the cost of hemodynamic impairment and the likely increased risk of VILI. In the Proseva trial, the average PEEP in the proning group was around 8 cmH_2O [5].

However, prone position may sometimes have either a neutral or even a deleterious effect on hemodynamics. This probably occurs when hemodynamic compromise is related to sepsis and not to RV overload. That said, hemodynamic impairment when "stabilized" should not be a

contraindication to prone positioning [16], while when non-stabilized (mean arterial pressure usually below 65 mmHg despite catecholamine infusion) it is the main reason intensivists do not do prone positioning [17].

In conclusion, besides its ability to limit VILI and improve oxygenation, proning also protects the pulmonary circulation, unloads the right ventricle and improves hemodynamics. This may explain in part its beneficial effect on the outcome. As this is especially true when hemodynamic compromise is related to RV failure, a simple recommendation for intensivists might be to evaluate RV function in supine position before and after turning prone ARDS patients if the right ventricle was previously overloaded. How RV failure could by itself be an indication for prone positioning, whatever the blood gases, remains to be determined in the future.

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Declarations

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References

1. Dres M, Austin P, Pham T, Aegerter P, Guidet B, Demoule A, Vieillard-Baron A, Brochard L, Geri G, CUB-REA group, (2018) Acute respiratory distress syndrome cases volume and ICU mortality in medical patients. Crit Care Med 46:e33–e40
2. Ferguson ND, Fan E, Camporota L, Antonelli M, Anzueto A, Beale R, Brochard L, Brower R, Esteban A, Gattinoni L, Rhodes A, Slutsky AS, Vincent JL, Rubenfeld GD, Thompson BT, Ranieri VM (2012) The Berlin definition of ARDS: an expanded rationale, justification, and supplementary material. Intensive Care Med 38:1573–1582
3. Papazian L, Aubron C, Brochard L, Chiche JD, Combes A, Dreyfuss D, Forel JM, Guerin C, Jaber S, Mekontos-Dessap A, Mercat A, Richard JC, Roux D, Vieillard-Baron A, Faure H (2019) Formal guidelines: management of acute respiratory distress syndrome. Ann Intensive Care 9:69
4. Writing Group for the Alveolar Recruitment for Acute Respiratory Distress Syndrome Trial (ART) Investigators (2017) Effect of lung recruitment and titrated positive end-expiratory pressure (PEEP) vs low PEEP on mortality in patients with acute respiratory distress syndrome: a randomized clinical trial. JAMA 18:1335–1345
5. Guerin C, Reignier J, Richard JC, Beuret P, Gacouin A, Boulain T, Mercier E, Badet M, Mercat A, Baudin O, Clavel M, Chatellier D, Jaber S, Rosselli S, Mancebo J, Sirodot M, Hilbert G, Bengler C, Richecoeur J, Gainnier M, Bayle F, Bourdin G, Leray V, Girard R, Baboi L, Ayzac L, PROSEVA Study Group (2013) Prone position in severe acute respiratory distress syndrome. N Engl J Med 368:2159–2168
6. Papazian L, Munshi L, Guerin C (2022) Prone position in mechanically ventilated patients. Intensive Care Med 48:1062–1065
7. Jozwiak M, Teboul JL, Anguel N, Persichini R, Silva S, Chemla D, Richard C, Monnet X (2013) Beneficial effects of prone positioning in patients with acute respiratory distress syndrome. Am J Respir Crit Care Med 188:1428–1433
8. Vieillard-Baron A, Charron C, Caille V, Belliard G, Page B, Jardin F (2007) Prone position unloads the right ventricle in severe ARDS. Chest 132:1440–1446
9. Mekontso-Dessap A, Boissier F, Charron C, Begot E, Repesse X, Legras A, Brun-Buisson C, Vignon P, Vieillard-Baron A (2016) Acute cor pulmonale during protective ventilation for acute respiratory distress syndrome: prevalence, predictors, and clinical impact. Intensive Care Med 42:862–870
10. Gattinoni L, Vagginelli F, Carlesso E, Taccone P, Conte V, Chiumello D, Valenza F, Caironi P, Pesenti A (2003) Prone-Supine study group. Crit Care Med 31:2727–2733
11. Albert RK, Keniston A, Baboi L, Ayzac L, Guerin C, Proseva investigators (2014) Prone position-induced improvement in gas exchanges does not predict improved survival in the acute respiratory distress syndrome. Am J Respir Crit Care Med 189:494–496
12. Slobod D, Assanangkornchai N, Alhazza M, Mettasittigorn P, Magder S (2022) Right ventricular loading by lung inflation during controlled mechanical ventilation. Am J Respir Crit Care Med 205:1311–1319
13. Duggan M, McCaul C, McNamara P, Engelberts D, Ackerley C, Kavanagh B (2003) Atelectasis causes vascular leak and lethal right ventricular failure in uninjured rat lungs. Am J Respir Crit Care Med 167:1633–1640
14. Katira B, Giesinger R, Engelberts D, Zabini D, Kornecki A, Otulakowski G, Yoshida T, Kuebler W, McNamara P, Connelly K, Kavanagh B (2017) Adverse heart-lung interactions in ventilator-induced lung injury. Am J Respir Crit Care Med 196:1411–1421
15. Rouby JJ, Brochard L (2007) Tidal recruitment and overinflation in acute respiratory distress syndrome: yin and yang. Am J Respir Crit Care Med 175:104–106
16. Guerin C, Albert RK, Beitler J, Gattinoni L, Jaber S, Marini JJ, Munshi L, Papazian L, Pesenti A, Vieillard-Baron A, Mancebo J (2020) Prone position in ARDS patients: why, when, how and for whom. Intensive Care Med 46:2385–2396
17. Guerin C, Beuret P, Constantin JM, Bellani G, Garcia-Olivares P, Roca O, Meertens JH, Azevedo-Maia P, Becher T, Peterson J, Larsson A, Gurjar M, Hajjej Z, Kovari F, Assiri AH, Mainas E, Hasan MS, Morocho-Tutillo DR, Baboi L, Chretien JM, François G, Ayzac L, Chen L, Brochard L, Mercat A, Investigators of the APRONET Study Group, the REVA Network, the Réseau de Recherché de la Sciété Française D'anesthésie-Réanimation (SFAR-Recherche) and the ESICM Trials Group (2018) A prospective international observational prevalence study on prone positioning of ARDS patients: the APRONET (ARDS prone position network) study. Intensive Care Med 44:22–37